

Dark Matter Search with sub-keV Germanium Detectors at the China Jinping Underground Laboratory

Qian Yue ^a and Henry T. Wong ^b
(on behalf of the CDEX-TEXONO Collaboration[†])

^a Department of Engineering Physics, Tsinghua University, Beijing 100084, China.

^b Institute of Physics, Academia Sinica, Taipei 11529, Taiwan.

E-mail: ^a yueq@mail.tsinghua.edu.cn ; ^b htwong@phys.sinica.edu.tw

Abstract.

Germanium detectors with sub-keV sensitivities open a window to search for low-mass WIMP dark matter. The CDEX-TEXONO Collaboration is conducting the first research program at the new China Jinping Underground Laboratory with this approach. The status and plans of the laboratory and the experiment are discussed.

The theme of the CDEX-TEXONO research program is on the studies of low energy neutrino and dark matter physics. The current objectives are to open the “sub-keV” detector window with germanium detectors [1]. The generic “benchmark” goals in terms of detector performance are: (1) modular target mass of order of 1 kg; (2) detector sensitivities reaching the range of 100 eV; (3) background at the range of $1 \text{ kg}^{-1} \text{ keV}^{-1} \text{ day}^{-1}$ (cpkcd). The neutrino physics program [2] is pursued at the established Kuo-Sheng Reactor Neutrino Laboratory (KSNL), while dark matter searches will be conducted at the new China Jin-Ping Underground Laboratory (CJPL) [3] officially inaugurated in December 2010. The three main scientific subjects are neutrino magnetic moments, neutrino-nucleus coherent scattering, and dark matter searches. We highlight the status and plans of the dark matter program in this article.

There are compelling evidence that about one-quarter of the energy density in the universe is composed of Cold Dark Matter [4] due to a not-yet-identified particle, generically categorized as Weakly Interacting Massive Particle (WIMP, denoted by χ). A direct experimental detection of WIMP is one of the biggest challenges in the frontiers of particle physics and cosmology. The WIMPs interact with matter pre-dominantly via elastic coherent scattering like the neutrinos: $\chi + N \rightarrow \chi + N$. There may be both spin-independent ($\sigma_{\chi N}^{SI}$) and spin-dependent ($\sigma_{\chi N}^{SD}$) interactions between WIMP and matter.

The facility CJPL [3] is the deepest operating underground laboratory in the world, having ~ 2400 meter of rock overburden and tunnel drive-in access, as shown schematically in Figure 1, It is located at southwest Sichuan, China, reachable from the provincial international airport at Chengdu via a 50 min flight to Xichang followed by a 90 min drive on a private two-lane motorway. The laboratory is owned by the Ertan Hydropower Development Company, and managed by Tsinghua University, China. Excavation and construction of the first experimental hall (“Hall A”) of dimension 6.5 m(width)X6.5 m(height)X40 m(length) with 50 cm of concrete

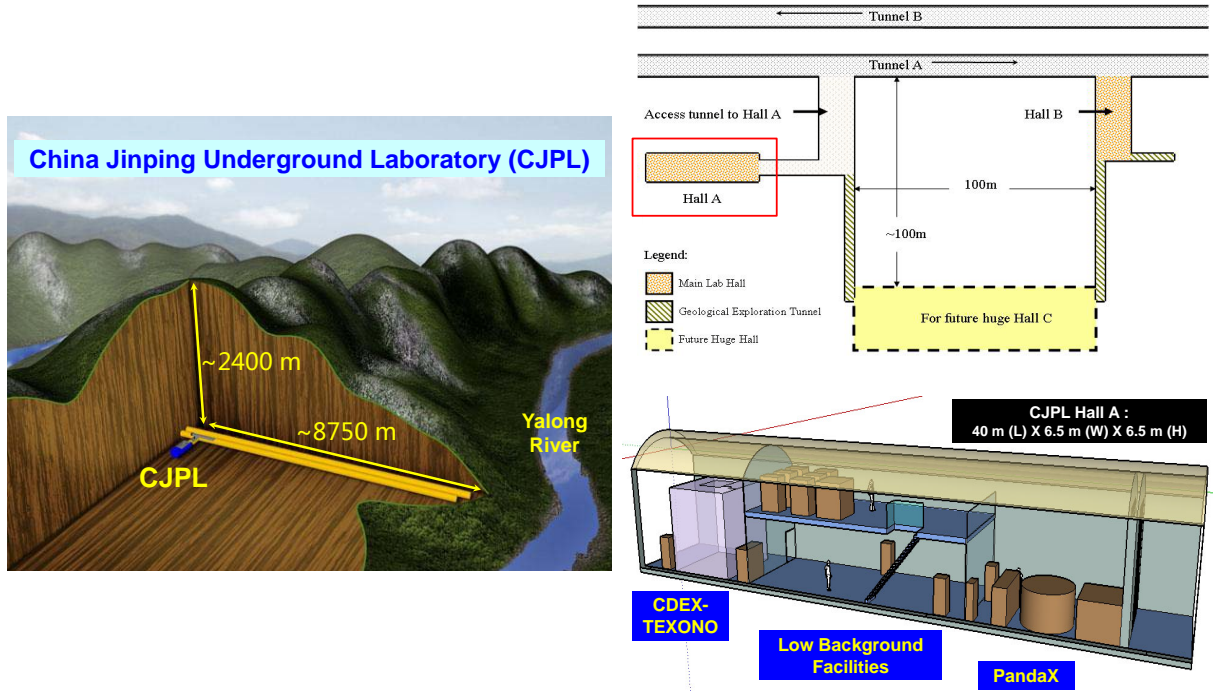


Figure 1. Schematics diagrams displaying the essential features of CJPL: Left— Geographical setting showing tunnel length and overburden; Right Top— Floor Plan of the present Hall-A and expected future expansions; Right Bottom— Layout of Hall-A, showing both CDEX-TEXONO and PandaX experiments.

lining was completed in summer 2010. By Fall 2011, the ventilation system, high-speed internet connections, as well as the necessary surface infrastructures (office and dormitory spaces, liquid nitrogen storage system) have been installed. There are intense efforts at CJPL to characterize the background. Measurements are being performed on the ambient radioactivity as well as fast and thermal neutron fluxes. Residual cosmic-ray events have been observed, at a rate (several events per month per square-meter) consistent with the expectation for a location with 2400 m rock overburden. The first generation experimental program at CJPL will include two projects: the CDEX-TEXONO experiment described here, and the dark matter project PandaX with liquid xenon detector. Future expansions of the laboratory are foreseen. New ideas are being discussed and explored.

An experiment with 100 eV threshold would open a window for Cold Dark Matter WIMP searches [4] in the unexplored mass range down to several GeV [1]. Based on data taken at KSNL with the 20-g prototype Ultra-Low-Energy Germanium detector (ULEGe), limits were derived in this low WIMP mass region improving over those from the previous experiments at $3 < m_\chi < 6$ GeV [5]. The $\sigma_{\chi N}^{SI}$ versus m_χ and $\sigma_{\chi N}^{SD}$ versus m_χ exclusion plots are depicted in Figures 2a&b, respectively. Also displayed are the various results defining the exclusion boundaries, together with allowed regions implied by the DAMA/LIBRA, CoGeNT and CRESST-II data [6, 7]. In particular, interpretations of the recent CoGeNT low-energy spectra as positive signatures of low-mass WIMPs [7] have stimulated intense theoretical interests and speculations on this parameter space.

Point-Contact Germanium detectors (PCGe) [8] offer sub-keV sensitivities with detector of kg-size modular mass, an improvement over the conventional ULEGe design. WIMPs with mass down to a few GeV can be probed. Intensive R&D efforts [9] are pursued to optimize the

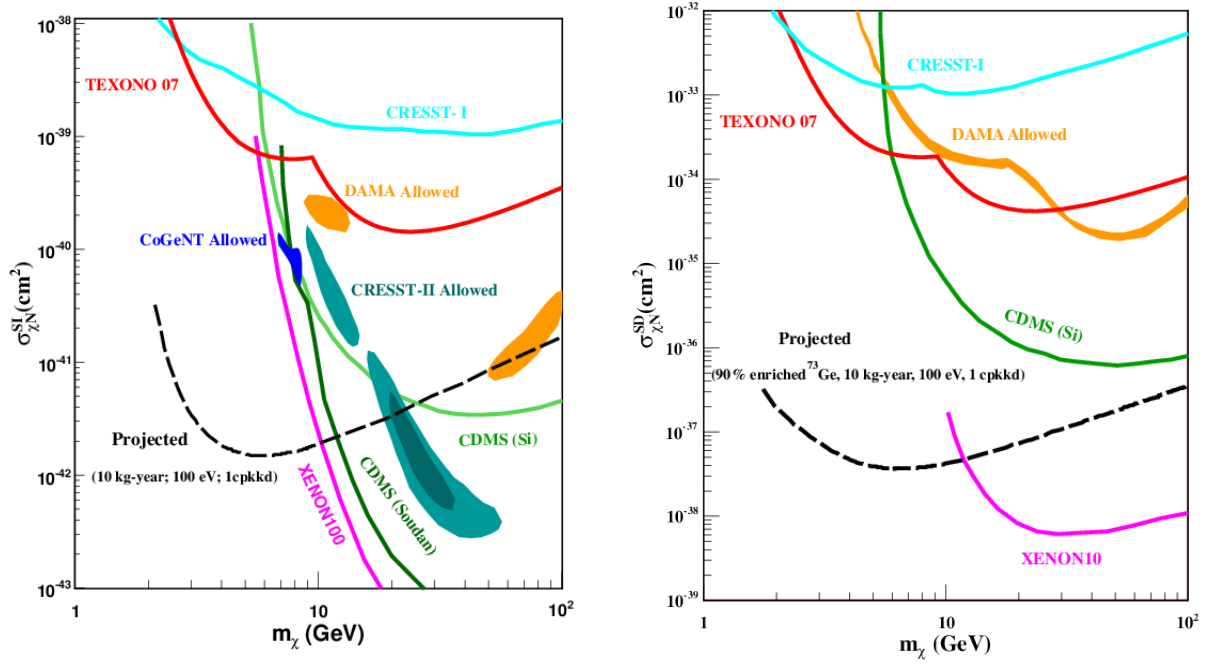


Figure 2. Exclusion plots of (a) Left: spin-independent χN and (b) Right: spin-dependent χN cross-sections versus WIMP-mass, displaying the KSNL-ULEGe limits [5] and those defining the current boundaries [4, 6]. The DAMA, CoGeNT and CRESST-II allowed regions [6, 7] are superimposed. Projected reach of experiments at benchmark sensitivities are indicated as dotted lines.

application of PCGe in dark matter searches, including programs on: (1) pulse shape analysis of near noise-edge events to extend the physics range, (2) pulse shape analysis of surface versus bulk events to characterize an important background channel, (3) sub-keV background understanding and suppression, and (4) fabrication of advanced electronics for Ge detectors.

A polyethylene (PE) shielding structure with thickness 1 m and interior dimension 8 m(length) \times 4.5 m(width) \times 4 m(height) has been constructed for the CDEX-TEXONO program at CJPL. A 20-g ULEGe array and a 1-kg PCGe have been installed within OFHC copper shielding inside this PE-housing. Data taking has commenced in February 2011. Design and construction of the next-generation PCGe array with total mass at the 10-kg range is proceeding. This new detector will be shielded and enclosed in a liquid argon chamber which serves as both cryogenic medium and active shielding and anti-Compton detector where the scintillation light will be read out by photomultipliers. Commissioning is planned in 2013. Potential reaches are depicted by dotted lines in Figures 2a&b. The projected sensitivities assume Ge detectors at 100 eV threshold (equivalent to about 500 eV nuclear recoils), 10 kg-year of exposure and that the achieved background level of the order of 1 cpkcd at the few keV range can be extrapolated down to threshold.

[†] The CDEX-TEXONO Collaboration consists of groups from China (Tsinghua University, China Institute of Atomic Energy, Nankai University, Sichuan University, Ertan Hydropower Development Company), Taiwan (Academia Sinica, Institute of Nuclear Energy, Kuo-Sheng Nuclear Power Station, National Tsing-Hua University), India (Banaras Hindu University) and Turkey (Middle East Technical University, Karadeniz Technical University). The authors are grateful to the generous and timely support provided by the participating institutes and their respective funding agencies.

References

- [1] Yue Q et al 2004 *High Energy Phys. and Nucl. Phys.* **28** 877; Wong H T et al 2006 *J. Phys. Conf. Ser.* **39** 266; Wong H T et al 2008 *J. Phys. Conf. Ser.* **120** 042013.
- [2] Wong H T et al 2007 *Phys. Rev. D* **75** 012001; Deniz M et al 2010 *Phys. Rev. D* **81** 072001.
- [3] Kang K J et al 2010 *J. Phys. Conf. Ser.* **203** 012028; Normile D 2009 *Science* **324** 1246; Feder T 2010 *Physics Today* **Sept 2010** 25.
- [4] Drees M and Gerbier G 2010 *Review of Particle Physics J. Phys. G* **37** 255, and references therein.
- [5] Wong H T 2008 *Mod. Phys. Lett. A* **23** 1431; Lin S T et al 2009 *Phys. Rev. D* **76** 061101(R).
- [6] Latest results presented at the TAUP-2011 Conference, these Proceedings.
- [7] Aalseth C E et al 2011 *Phys. Rev. Lett.* **106** 131301; Aalseth C E et al 2011 *Phys. Rev. Lett.* **107** 141301.
- [8] Luke P N et al 1989 *IEEE Trans. Nucl. Sci.* **36** 926; Barbeau P A, Collar J I and Tench O 2007 *JCAP* **09** 009.
- [9] Wong H T 2011 *Int. J. Mod. Phys. D* **20**, 1463.